3D urban transport environment

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Abstract. The paper investigates issues related to the solution of problems in the development of public transport infrastructure in urban agglomerations. The opportunities of further development of the existing typical city public transport infrastructure have been studied. The conclusion about the possibility of reforming the existing typical urban public transport infrastructure is drawn. It is proposed to use the available airspace together with the ground and underground public transport as a direction for the development of urban public transport infrastructure. The formation of an urban transport 3D environment is studied. It is shown that the joint application of all three urban transport environments will significantly expand the potential of urban public transport infrastructure. The possibility of using ultralight aircraft as an air vehicle is considered. It is proposed to use new types of aircraft as air vehicles. The prototype of an aircraft based on cylindrical vane propellers under the code name "Cyclolet" is described. Its flight technical characteristics are given. The conclusion about the possibility of using an aircraft of the "Cyclolet" type on the basis of cylindrical vane propellers as an air vehicle in the organization of permanent public transportation in urban agglomerations in the Russian Federation and abroad is drawn.

1 Introduction

The existing transport infrastructure largely delays the development of urban agglomerations. At the same time, the situation in the transport sector in urban agglomerations is not improving despite the increasing car ownership rate of the population living there. These problems exist not only in the Russian Federation, where more than 74% of the total population live in the cities, but also abroad [1].

The solution of this problem in the Russian Federation is one of the most important tasks. In such regulatory documents as "On the National Development Goals of the Russian Federation for the period up to 2030", "On the National Security Strategy of the Russian Federation", "The Transport Strategy of the Russian Federation until 2030 with a forecast for the period up to 2035" it is stated that the solution of these problems is of primary importance [2-4].

The main reason of the existing negative phenomena in the urban transport infrastructure is that the development of public ground transport in the settlements is

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limited by the lack of free space. Most of the free territory of cities is in private ownership, which greatly limits the possibilities of its usage.

In turn, the widespread use of underground public transport is largely limited by the high cost of building underground utilities and their subsequent maintenance. All this does not allow proper covering the territory with underground communications even in large urban agglomerations, which can be considered financially secure.

In general, it can be concluded that the existing transport urban infrastructure has reached its definite limit of development. Nowadays it is becoming clear that new mechanisms are required to give impetus to the development of the transport infrastructure of urban agglomerations.

Such an impulse can be given by taking a decision to use airspace over cities which is currently not involved in any way in urban population transportation. We mean the formation of a 3D transport environment (ground, underground and air).

2 Purpose of research

The main purpose of research is to find ways to increase the mobility of the population in urban agglomerations by means of airspace usage. The use of airspace together with ground and underground public transport (3D environments) will greatly expand the potential of the existing transport infrastructure of the cities. This will make it possible to more effectively redistribute existing passenger flows, which will significantly improve the overall mobility of the population of urban agglomerations.

3 Material and methods of research

The use of airspace in urban agglomerations requires foundation for applying certain types of aircraft. There are certain problems here. The use of super-light aircraft and helicopters as aircraft for urban conditions is quite problematic for a number of reasons. The main one is the technical reason.

An aircraft of even a super-light class requires an appropriate runway. In fact, what is meant here is the availability of a mini airfield, but with the required infrastructure facilities there, including hangars for routine maintenance, filling stations with fuel storage tanks, etc., that is quite difficult to have in the limited territorial conditions of urban agglomerations.

In its turn, a light-class helicopter has much fewer disadvantages compared to the aircraft. The main restriction on the mass application of helicopters in urban agglomerations is the high noise level, which is absolutely unacceptable in urban conditions. In addition, the helicopter also requires platforms equipped with certain necessary attributes for landings and takeoffs, although of smaller sizes.

But, in general, the main reason for the shortcomings of both the aircraft and the helicopter is the type of the propulsor they use, namely the propeller. The propeller used in the whole limits the capabilities of the propulsor, both for the propeller (for airplanes) and for the main rotor (for helicopters).

All this allows drawing a conclusion that the use of aircraft, helicopters and their hybrids (convertaplanes, multirotors, etc.) as air vehicles for the development of transport infrastructure in urban agglomerations at this stage of technology development is not of a particular interest.

In order to justify the use of other aircraft as vehicles in urban conditions, it is necessary to formulate the basic requirements to them. They are the following.

Firstly, it is the mandatory vertical capability of an aircraft. This makes it possible to have modes of hovering, horizontal and vertical maneuvering in a limited space, etc., which is especially important in urban conditions.

Secondly, the low noise level produced during the operation of the aircraft will allow using the aircraft on a massive scale in urban environments without violating medical and other requirements. Besides, it will allow forming constant air passenger traffic.

Thirdly, the compact dimensions of the aircraft will make it possible to organize more places for landing and take-off. All this will ensure the walking accessibility of take-off and landing sites in the urban agglomeration, and hence higher mobility of the population living there.

Fourthly, the possibility of parking on the buttresses of buildings and lattice platforms of any height level will allow significant increasing the number of places where passengers of urban agglomerations can be discharged or enplaned.

Fifthly, a high degree of safety in the aircraft operation which include, on the one hand, the minimum number of dangerous rotating parts in an aircraft and on the other hand, the high reliability of the operation of the aircraft itself.

Sixthly, the presence of an emergency automatic rescue system working both in automatic and semi-automatic mode. It will significantly expand the volume of passenger traffic in an urban agglomeration.

Seventhly, the possibility to operate an aircraft in a partial or complete unmanned mode will not only reduce the costs of operating it, but will also make it possible to integrate a specific aircraft into the current passenger flow in an urban agglomeration. This possibility will reduce the cost of the current aircraft operation.

Eighthly, the air vehicle must comply with all environmental requirements imposed on it during the production, operation and further utilization. Only those materials that are harmless to the ecology of urban agglomerations should be used in its construction. In fact, it is necessary to largely abandon polymer composite materials.

Of course, there are some other requirements, which should be imposed to the aircraft in the process of its operation in urban conditions. Besides, some additional requirements may appear, taking into consideration changes in the national and international legislations. But at present, the above requirements are the most significant ones.

The search for new types of aircraft for the application in urban environments requires additional research. But we can already say that there are prototypes of aircraft that use a different type of propulsion.

If the working bodies (propellers) of airplanes and helicopters move in a plane perpendicular to the axis of rotation, then the working bodies (blades) of new prototypes of aircraft trace a cylindrical trajectory parallel to the axis of rotation. The most famous among them are the Savonius rotor (uses the Magnus effect) and the Darrier rotor (a type of low-pressure turbine).

The most promising variant of this type of propeller for the application in the aircraft in urban agglomerations is a vane propeller. Its idea was proposed back in 1681 by the English inventor Robert Hooke.

The aircraft of the engineer Strandgren, the aircraft "Cyclogyro" (the author is E. A. Schroeder); the cyclogyro by Haviland Platt, the cyclogyro by John B. Whitley, A. Rohrbach's cyclogyro, the cycloplane by Frederick C. Kirsten and a number of other aircraft were the most famous aircraft using vane propellers designed in the twentieth century [5-7].

At the beginning of the 21st century, research work on the use of vane propellers started again, both in the Russian Federation and in the European Union, the Republic of South Korea, the USA, the People's Republic of China, Israel and a number of other countries of

the world. A number of prototype aircraft using vane propulsor were designed and tested there.

The Austrian company IAT21 has achieved the greatest practical success. In 2006, this company tested an aircraft powered by an electric motor weighing 20 kg with a payload of 10 kg, and in 2012 it tested an aircraft using a diesel engine with a total weight of 200 kg and a payload of 100 kg [8].

The success of the Austrian company made it possible to launch a project to develop air transport in cities within the framework of the European Union (EU). The appearance of this project in the EU confirms the validity of the idea to use airspace in Russian urban agglomerations for solving transport problems. The importance of the idea to use vane propellers in air transport is also confirmed by a number of decisions of Russian state bodies responsible for conducting fundamental and applied research in the country. In particular, in 2017 the Foundation for Advanced Research Projects organized a competition for the design and construction of a demonstrator of a vertical or ultra-short takeoff and landing aircraft using aerodynamic force created by the cyclic movement of the blades.

61 applicants submitted applications for participation in the competition. OJSC "Kamov", OJSC "Moscow Helicopter Plant named after M. L. Mil", Siberian Aeronautical Research Institute named after S. A. Chaplygin and a number of other organizations were among them. The winner of the competition became the little-known organization "Flash-M" LLC, which represented the "Arey" research group. The group had a certain design and technological reserve for work in this direction. But due to a number of organizational and other reasons the "Arey" research group had to withdraw from the competition, which led to the cancellation of the competition results.

At present, the work on the creation of an air vehicle based on a vane propeller in the Russian Federation has been carried out separately within the framework of the Foundation for Advanced Research Projects and the "Arey" research group. Such a situation, of course, does not benefit the project for the creation of an air vehicle based on the use of a vane propeller in the Russian Federation.

4 Research results and discussion

It must be said that the activities of the Foundation for Advanced Research Projects are to a certain extent closed in terms of obtaining information about the results of ongoing research and development (R&D) work to create a new aircraft based on the use of a vane propeller. But the research and development work carried out by the "Arey" Research Group on the design of vane propellers for aircraft is still available to interested parties.

Thus, the research group "Arey" stated that in the process of R & D they obtained a number of important results that formed the basis of the theory and practice of the operation of vane propellers. These include understanding of the role of geometric ratios of the rotor elements and the number of blades. The limits of regulation of attack angles and the thrust vector deflection were determined. There appeared understanding of the strength requirements for the structure and the rigidity of its parts, etc. All this as a whole gives a certain possibility of designing aircraft of various dimensions using a vane propeller, from an unmanned version to those transporting several dozen passengers over long distances (Fig. 1) [9, 10].

In the process of R&D, the "Arey" research group proposed a conceptual image of a two-seat aircraft using vane propellers. It received the name "Cyclolet". The aircraft has a three-rotor aerodynamic configuration. Between the two front cylindrical rotors there is a capsule-cabin. The third cylindrical rotor is located in the aft part of the capsule-cabin. The aircraft has a skid landing gear. The control of the apparatus evolutions is provided by an

eccentric mechanism that changes the direction of the thrust vectors of the cylindrical rotors (Fig. 2) [9-11].

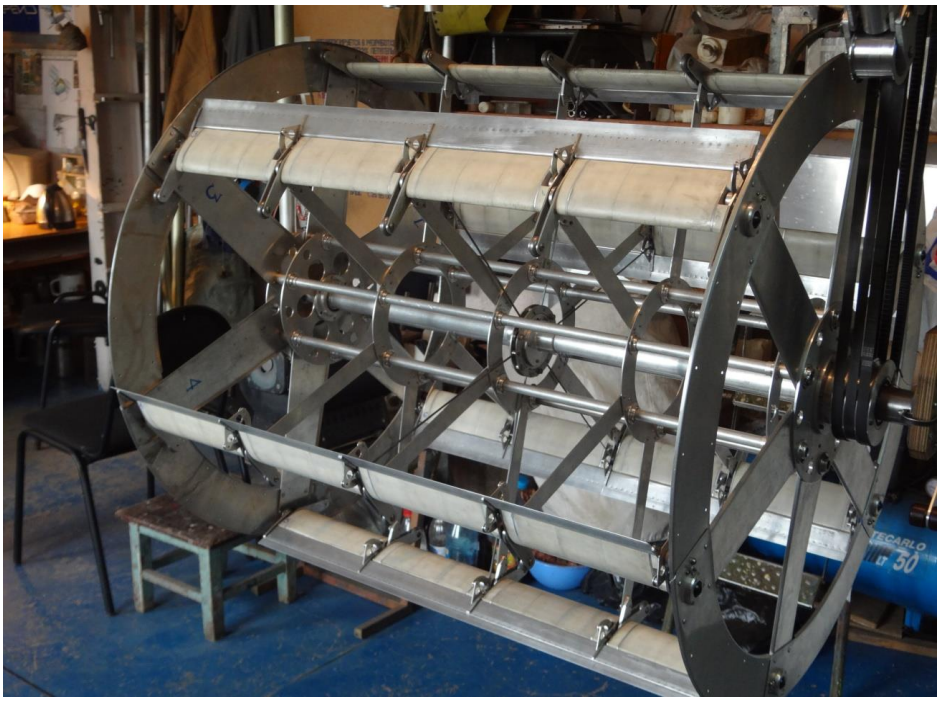

Fig. 1. Cylindrical vane propeller with a cylinder diameter of 0.78 m.

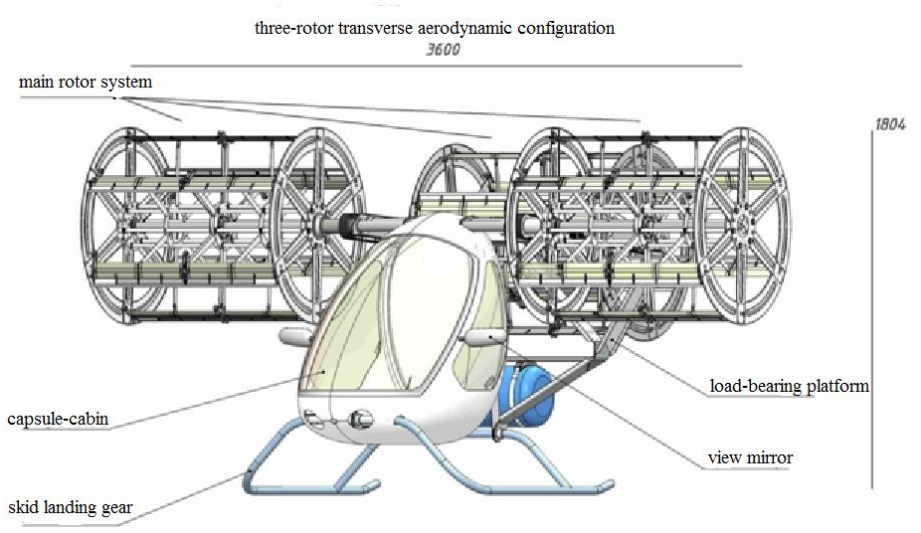

Fig. 2. Vertical takeoff and landing aircraft "Cyclolet" with a carrier and traction system based on vane propellers.

Certain flight technical characteristics of the promising aircraft "Cyclolet" were obtained in the process of carrying out bench tests. These flight characteristics include the following.

The possibility of mooring the aircraft "Cyclolet" to the vertical planes of buildings, structures, etc. has been proved. There is no such possibility as far as modern helicopters and other aircraft are concerned. This characteristic of the aircraft greatly expands the possibilities of its application and is related not only to the transportation of passengers. The aircraft can also be used in rescue and other kinds of work in urban areas.

The possibility of parking this aircraft on the buttresses of buildings, as well as lattice platforms of any height level, is substantiated. This fact greatly increases the number of places where an aircraft can be waiting to be put into service.

The aircraft "Cyclolet" has a low noise level during operation. According to the most conservative estimates this level is 2-3 times lower than the noise level produced by a helicopter. High accuracy of landing with a strong external disturbance of the environment is an important technical characteristic of the aircraft "Cyclolet". Deviation will be no more than 1 meter, which is important in urban conditions.

Another unique technical feature of the aircraft "Cyclolet" is its high stability and controllability at wind speeds up to 20 m/s. It is especially important for urban environments, where, due to the peculiarities of the architecture, certain and sometimes unexpected air flows can occur at the most inconvenient time, which can lead to loss of controllability of the aircraft.

It has been proven that the vertical rate of climb of the aircraft "Cyclolet" can be up to 10 m/s. For urban agglomerations this characteristic is also important.

A technical feature of the aircraft "Cyclolet" is the possible range of speeds in horizontal flight from 0 to 200 km/h with a range of over 300 kilometers. This allows not only operating the aircraft without refueling for a longer distance in an urban agglomeration but also organizing suburban transportation, which is no less important in modern urban conditions.

The total resource of operation of the aircraft "Cyclolet", which amounted to more than 5000 hours, was experimentally substantiated. The time between failures of the main elements was also determined. It was over 2000 hours. These characteristics allow speaking about the possibility of using the aircraft "Cyclolet" to organize permanent routes for the transportation of passengers in urban agglomerations [9, 10].

5 Conclusions

The list of above main characteristics of the aircraft "Cyclolet" is not final. Additional research and development work is needed. The influence of working rotors on each other has not yet been fully studied. This characteristic may change with an increase in their number in an aircraft. It is also necessary to optimize the overall dimensions of the rotors themselves, etc. [12, 13]. Additional R&D requires financial resources and time. Therefore, it is necessary to unite the efforts of the state and specialists in this field for more efficient work.

But nevertheless, the obtained characteristics of the vertical take-off and landing aircraft "Cyclolet" with a carrier and traction system based on vane propellers allow concluding that this design solution of a promising aircraft can be taken as the basis for its use in urban conditions. Its widespread use in urban agglomerations will make it possible to form a 3D urban transport environment not only in the Russian Federation, but also abroad.

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